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Status of US Testing of the High Performance Hall System SPT-140 Hall Thruster

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Abstract

The High Performance Hall System (HPHS) program supports the development and flight qualification of a 4.5 kW electric propulsion system that includes the SPT-140 Hall thruster. The Air Force Research Laboratory (AFRL) and International Space Technology, Inc. (ISTI) are co-funding the HPHS program which is being conducted by a team led by Atlantic Research Corporation (ARC). The team includes ISTI, Experimental Design Bureau Fakel (Fakel), and Space Systems Loral (S/SL). The Research Institute of Applied Mechanics and Electrodynamics (RIAME) also provided support for this project. The SPT-140 is being designed, developed, manufactured, and tested by Fakel in Kaliningrad, Russia, where extensive performance testing and advanced development have been performed. In addition to the testing in Russia, a suite of experiments on the development model and the qualification model thrusters, sponsored by the US Government, has occurred during 1999 and is scheduled to occur in 2000. These experiments include thruster performance, plume characterization, electromagnetic compatibility, and life characterization. This paper presents the status of government testing of the SPT-140 in the United States.

Introduction

Due to their high specific impulse and thrust efficiencies, Hall thrusters are now being considered for use on commercial, research, and military spacecraft. This technology provides economic advantages for a number of missions and its use can be translated into lower launch mass, longer time on station, or larger payloads. The US Air Force, NASA, and industry have shown interest in high power (~5 kW) Hall thruster systems as spacecraft have grown both in size and electrical power capacity. The High Performance Hall System (HPHS) program is developing a 4.5 kW Hall propulsion system that provides significant payoffs for station-keeping, repositioning, and orbit raising applications.

Program Description

The Air Force Research Laboratory (AFRL) and International Space Technology, Inc. (ISTI) are co-funding this cost shared contract (56% government, 44% contractor) under the auspices of the Integrated High Payoff Rocket Propulsion (IHPRPT) initiative. Atlantic Research Corporation (ARC) is the prime contractor. The propulsion system includes the thruster, power processing unit (PPU), propellant management assembly (PMA), and simulated spacecraft hardware. The Experimental Design Bureau Fakel, a Russian

Testing at NASA Glenn Research Center

The series of tests performed at GRC were completed during August 1999. All tests were performed in Chamber 6 consisting of a 7.5 m diameter, 18 m long stainless steel vacuum chamber pumped by 12 LN_2 cooled CVI TM-1200 reentrant cryopumps with a total pumping speed of approximately 500,000 l/s on xenon and a base pressure of 10^{-6} Torr as measured on an ionization gauge calibrated for N_2.

The first tests consisted of performance measurements of the DM thruster as measured on an inverted pendulum thrust stand. A preliminary analysis of these measurements indicates that the thruster performance exceeds that measured with an engineering model SPT-140 at NASA GRC [2]. Performance testing was also done at a number of pumping speeds and background pressures which was accomplished by selectively shutting down cryopumps. A total of four background pressures/ pumping speeds were examined. Performance measurements at higher background pressures indicated that some entrainment of background neutral xenon was occurring. The additional performance testing at a variety of background pressures will allow for an extrapolation of the actual performance at zero background pressure. Figure 2 shows the SPT-140 mounted on the thrust stand at GRC.

During performance testing, ion current density measurements were performed at a distance of 1 m from the exit plane [3]. These measurements were also performed for a variety of pumping speeds/background pressures and characterize the plume profile and how it varies with background pressure.

The second series of tests performed at GRC examined EMI produced by the SPT-140 Hall thruster. Measurements of the EMI produced by the SPT-140 were performed over five frequency regimes: 10 kHz - 32 MHz, passive rod; 32 MHz - 200 MHz, biconical antenna; 200 MHz - 350 MHz, broadband dipole; 350 MHz - 1 GHz, log period dipole; and 1 GHz - 18 GHz, double ridge guide horn. All measurements were made at a power of 3.0 kW (300 V, 10 A).

The final set of measurements performed at GRC consisted of plume contamination testing of the Hall thruster operating at 3.0 kW (300 V, 10 A) and a background pressure of 1.8×10^{-5} Torr for a period of 100 hours. A GRC test plan, derived from SPT-140 test requirements and prior SPT-100 testing was used [4]. The test consisted of 26 samples and several controls to determine the extent and distribution of contaminant deposition. A majority of the samples consisted of solar array cover glass, but other solar array materials and thermal control samples were also included. The samples were placed on a stainless steel ring with a 2.0 m diameter and housed in line-of-sight tantalum collimators similar to those used in previous testing of the SPT-100 at GRC [4].

The mass, transmittance, reflectance, and emittance of the cover glass samples before and after plume exposure, along with the control sample will be examined. The other samples will also be examined. Profilometry and chemical analyses of the samples will provide additional information, as will depth profiling. Combined, these data will provide insight on the sequence of events that occur leading to contaminant deposition. Finally, the impact of contaminant on component performances will be evaluated.

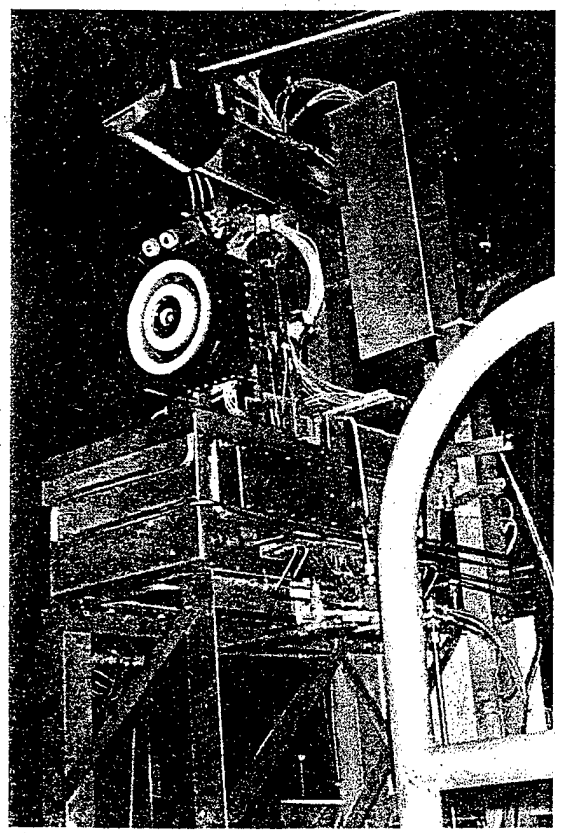

Fig. 2. Photograph of SPT-140 mounted on thrust stand at NASA GRC.

m and four 0.6 by 2.5 m helium panels cooled to approximately 20 K. These panels are in turn shrouded by a system of Polycold® baffles to insulate the helium refrigerated panels from heat sources such as the ambient chamber walls and the Hall thruster plume. The total pumping speed of the facility is estimated to be approximately 350,000 l/s on xenon and provide a background pressure better than $2x10^{-5}$ Torr during operation of the SPT-140. Construction is on schedule and the chamber will be completed by January 2000.

The vacuum system will be instrumented to monitor the environment in which the test will be carried out. Two redundant ionization gauges and two cold cathode gauges will be used to monitor the background pressure during the test. All pressure measurements will be traceable to National Institute of Standards and Technology (NIST) standards. Pressure measurements will be supplemented with two residual gas analyzers which will monitor the relative proportions of background gases in the vacuum facility.

The life test of the HPHS will be extensively instrumented. The primary mission of the life test diagnostics package will be to monitor the performance of the SPT-140. This will be accomplished with an inverted pendulum thrust stand previously used in tests at AFRL [9]. The thrust stand has full scale of 360 mN and an accuracy better than ±3 mN.

In addition to the primary mission of performance measurement, the life test diagnostics will also measure a variety of other thruster characteristics. In order to provide an indication of how the plume divergence changes over the lifetime of the thruster, a probe rake with seven guarded Faraday probes similar to those previously used at GRC and PEPL will be placed approximately 1 m from the thruster exit plane. The probes will characterize the ion current density of the plume with sweeps occurring periodically during testing. To measure and record the erosion of the SPT-140 insulator, a comparative photographic system will be utilized. A charge coupled device (CCD), 1064 by 1064 elements with a resolution better than 200 μm, will capture images of the thruster front face through a shuttered view port. The port is approximately 3 m from the thruster exit plane and angled at 45° from the vacuum facility centerline. The images of the thruster will be correlated to produce a time history of the erosion of the SPT-140 insulator throughout the life test. A photograph of the vacuum facility is shown in Fig. 4.

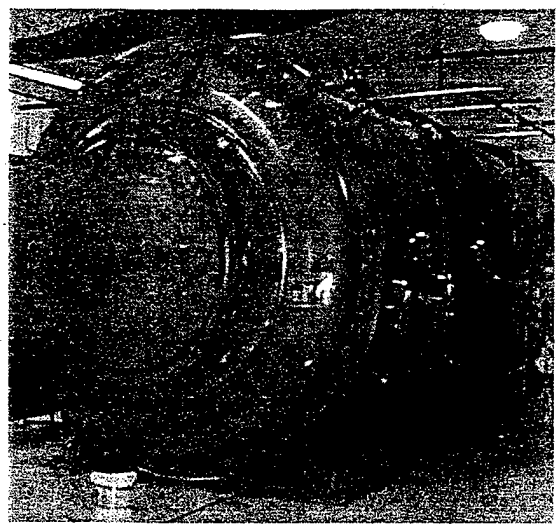

Fig. 4. New AFRL vacuum facility for HPHS life extended duration life testing.

Due to the long duration of the testing at AFRL, the vast majority of the diagnostics will be automated. Thruster operations will be monitored and recorded using an Hewlett-Packard HP34970A data logger that will allow the setting of trip points which will be used to ensure the test remains within the specified parameters. The entire thrust measurement procedure will be automated, including the measurements and periodic calibration of the thrust stand. The Faraday probe measurements of the plume will also be automated such that no operator interaction is required to complete the diagnostic program. The erosion measurements will also be automated in a similar manner. The diagnostics system control will consist of a PC running the National Instruments LabView® software package which will provide the logic to operate the diagnostics. The diagnostic computer will ultimately control the test by interacting with the computer controlling the PPU.

An exciting technology transition opportunity has arisen concerning the HPHS SPT-140 Hall thruster. MILSATCOM has approved an extended duration orbit transfer (90 days) for the Advanced EHF satellite slated to replace the current MILSTAR system starting in 2006. The Advanced EHF program is a defined near term priority for the Air Force Space Command [10]. The HPHS would provide both north-south station-keeping and orbit transfer operations. Currently, the SPT-140 is being evaluated at the Aerospace Corporation for this mis-